University at Buffalo
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QCD@LHC 2019

Measurement of the strong coupling constant by CMS

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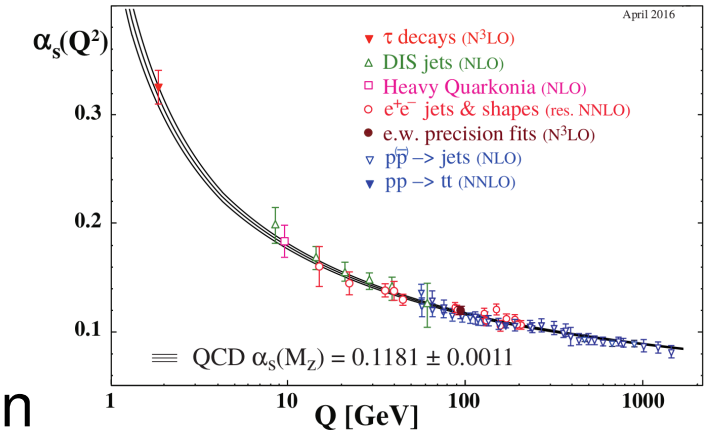
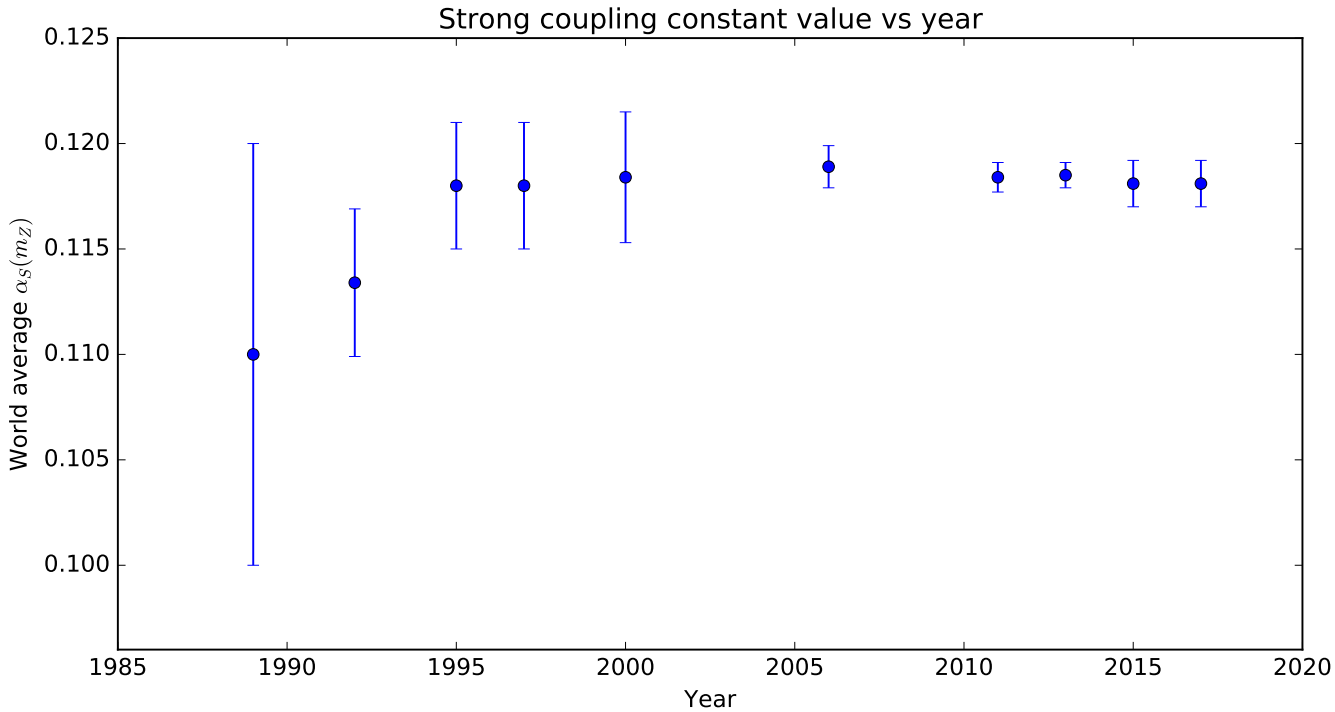
The strong coupling constant α_S

- Not a constant but running wildly
  - Leads to confinement and asymptotic freedom of QCD
- The only free parameter in QCD
  - Considering quark masses fixed
- Enters every QCD theory calculation
  - Contributes *e.g.* to Higgs production σ calculation
    - ⋆ Affects also BSM searches looking for deviations in Higgs σ!
  - Precision measurement important but hard
  - $\delta(\alpha_{EM})$ = 0.2 parts per billion, $\delta(\alpha_S)$ = 10^7 ppb (~1%)
- Determined in lattice QCD or collider experiments
  - Best precision from lattice calculations, but reliability of uncertainty estimates under discussions



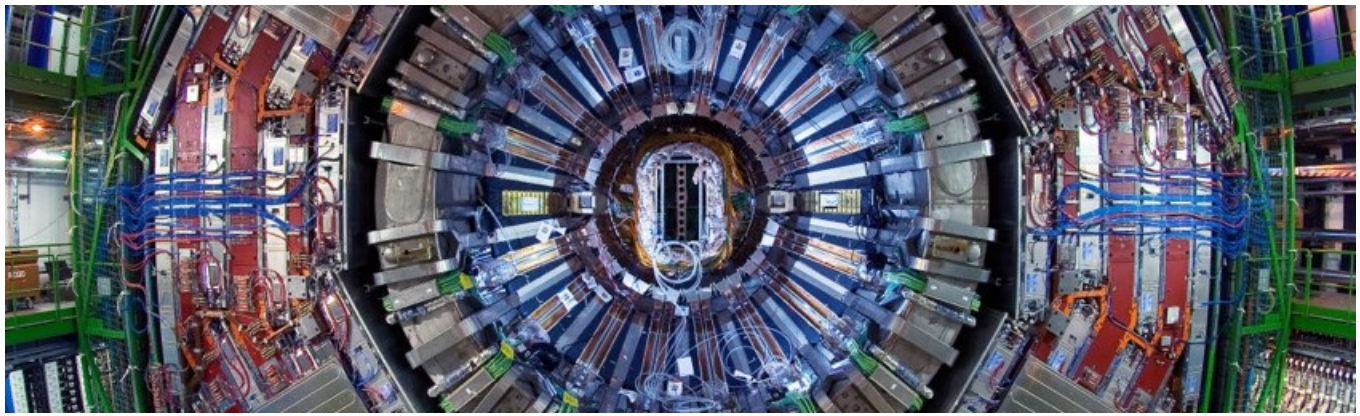
History of α_S measurements



- First known world average value from G. Altarelli in 1989
  - Heavily extrapolated to m_Z, but still within 1σ!
- Lattice calculations and collider experiment results combined in world averages
  - Uncertainty estimation and choosing results not trivial
- Converging to $\alpha_s(m_Z) = 0.118$, but uncertainty grown

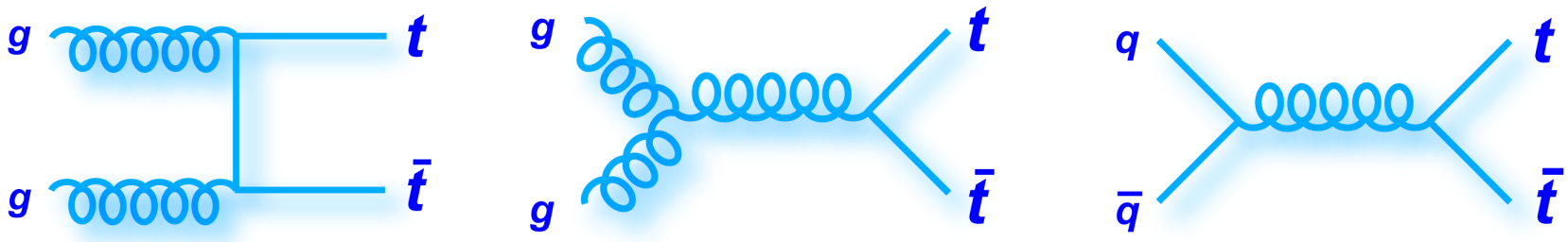
Measurements from CMS

- CMS has produced $\mathcal{O}(10)$ α_s extractions with 7–13 TeV
- Here I present four interesting and/or recent results
- Arbitrary choice, apologies if your favourite not included
- Following analyses made the cut this time:
  - α_s extraction from $t\bar{t}$ cross section @ 7 TeV
  - α_s extraction from jet substructure in $t\bar{t}$ events
  - α_s extraction from triple-differential dijet cross section
  - α_s extraction from $t\bar{t}$ cross section @ 13 TeV

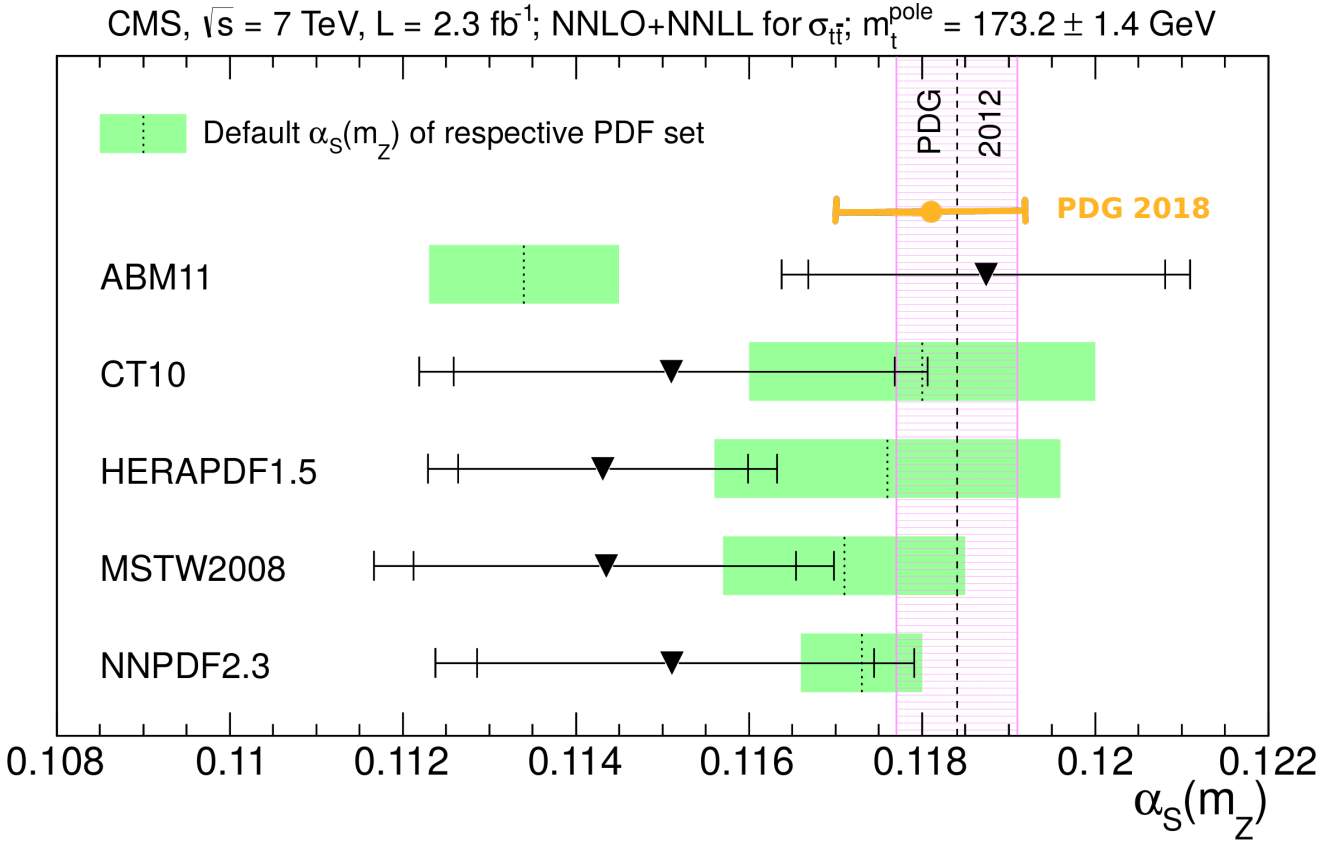


α_s from $t\bar{t}$ production cross section

- Inclusive $\sigma_{t\bar{t}}$ from a previous CMS analysis is compared to NNLO QCD predictions
  - 2.3fb^{-1} @ 7 TeV, arXiv:1208.2671
- $\alpha_s(m_Z)$ determined by fixing m_t (and *vice versa*)
  - Favoured α_s from a PDF fit χ^2 scan
- Five different NNLO PDF sets tested
- First $\alpha_s(m_Z)$ result with NNLO at a hadron collider and the first α_s extraction using top-quark production



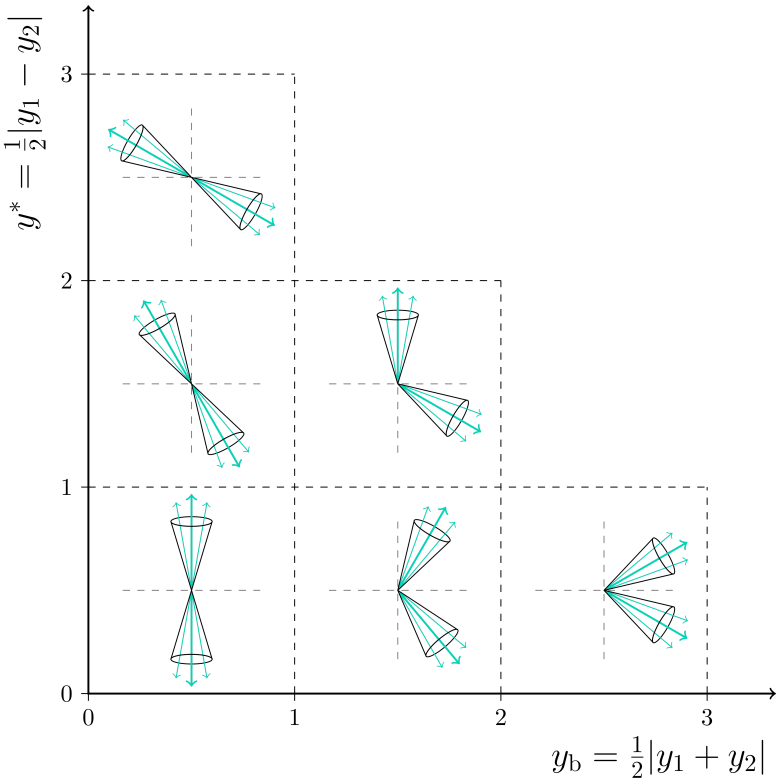
Results



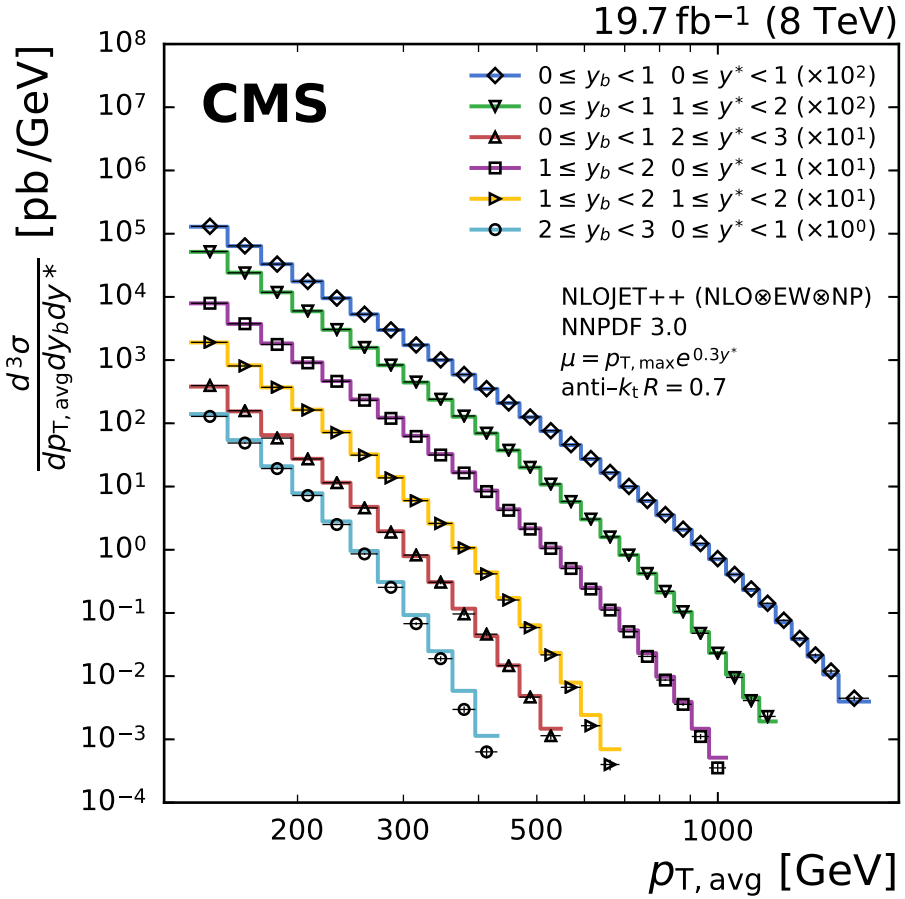
- Extracted α_s values mostly below the 2012 world average
  - ... but world average came down from that!
- With the latest world average results ~within 1 σ
- Main result from NNPDF2.3: $\alpha_s(m_Z) = 0.1151^{+0.0028}_{-0.0027}$

α_s from triple-differential dijet cross section

- Triple differential σ_{dijet} measured from dijet events with 20fb^{-1} of 8 TeV data
  - $\sigma_{\text{dijet}}(p_{\text{T}}^{\text{ave}}$, rapidity separation y^*, boost $y_b)$
- Dijet processes sensitive to α_s
- PDF fits done with the measeured σ_{dijet} and DIS data from HERA
  - $\alpha_s(m_Z)$ inferred by repeating PDF fit with it as a free parameter



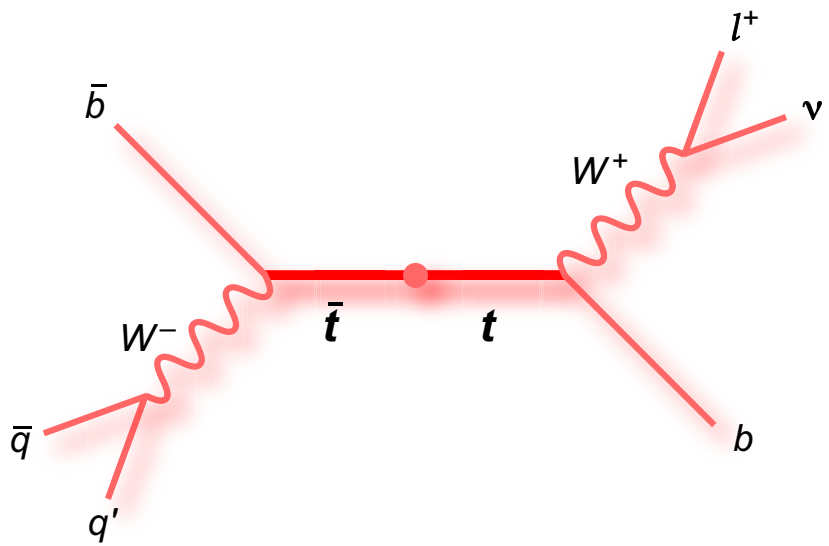
Results



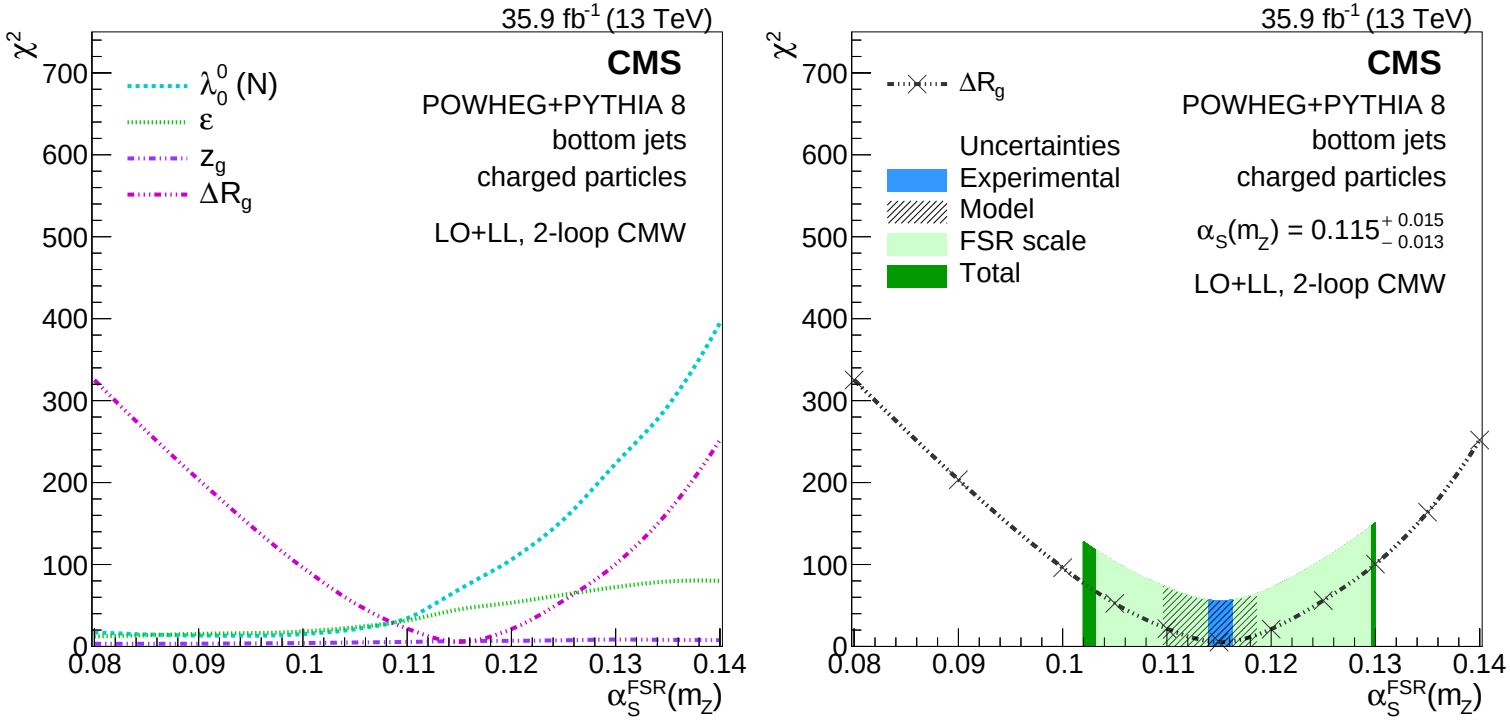
- Measured triple-differential σ_{dijet} agree well with the NLOJET++ and NNPDF 3.0 prediction
  - Some deviation in the boosted region $y_b > 1$
- Extracted strong coupling: $\alpha_s(m_Z) = 0.1199^{+0.0034}_{-0.0025}$
  - Theory scale uncertainty dominating: $^{+0.0031}_{-0.0020}$

α_s from jet substructure data in $t\bar{t}$ events

- Measurement of jet substructure in $t\bar{t} \rightarrow \ell^{\pm}$ + jets events
  - Using the full 2016 dataset; 36 fb^{-1} at $\sqrt{s}$ = 13 TeV
- Jet substructure sensitive to the strenght of QCD
  - Here angle between subjets most sensitive
- $\alpha_s(m_Z)$ extracted at LO+LL theory accuracy
  - Measured distributions compared to POWHEG + PYTHIA8 predictions, 'preferred' α_s determined in χ^2 scan



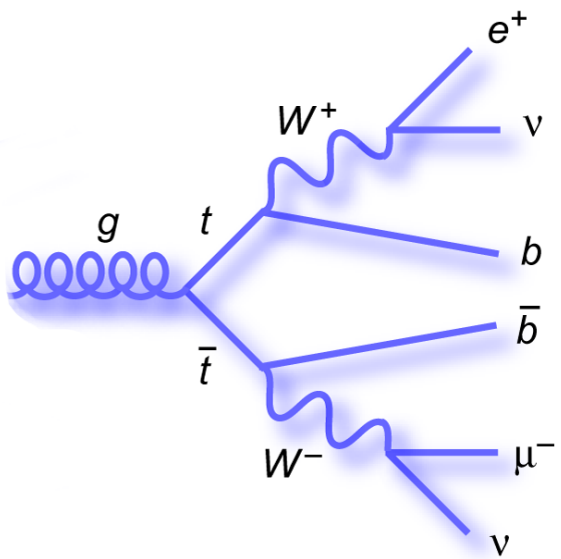
Results



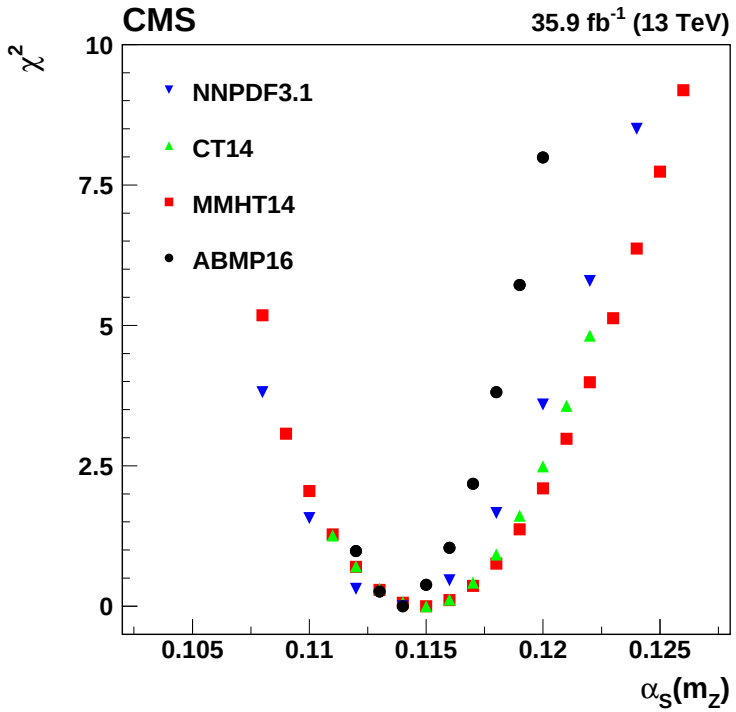
- Out of many jet substructure variables, the angle between groomed subjets ΔR_g gives the best α_s extraction result
- α_s is determined from a FSR-process
- Result: $\alpha_s = 0.115^{+0.015}_{-0.013}$
  - Precision limited by FSR scale unc. in PYTHIA8, $^{+0.014}_{-0.012}$

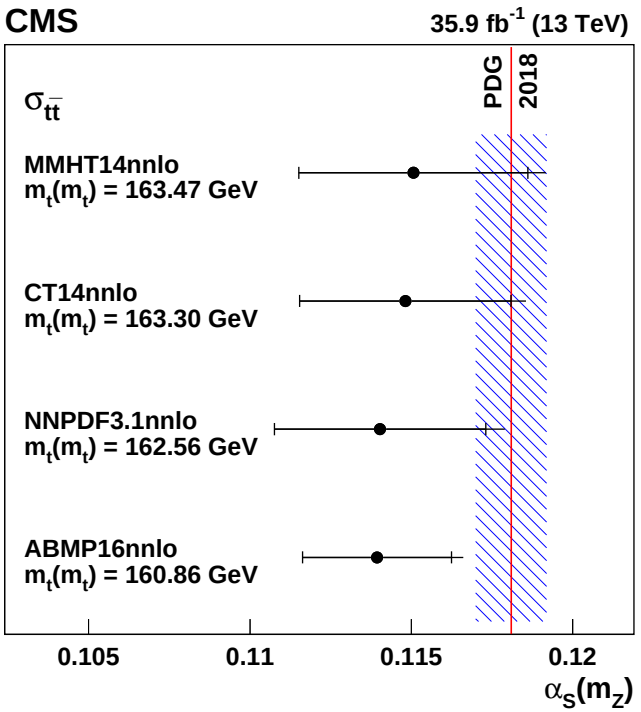
α_s from $t\bar{t}$ production cross section (revisited)

- Inclusive $\sigma_{t\bar{t}}$ is measured from dileptonic $t\bar{t}$ events
  - Full 2016 dataset; 36 fb^{-1} @ 13 TeV
- $\alpha_s(m_Z)$ determined by fixing m_t (and *vice versa*) and comparing obtained $\sigma_{t\bar{t}}$ to NNLO prediction
  - Preferred α_s value from a χ^2 scan
- Four different NNLO PDF sets tested



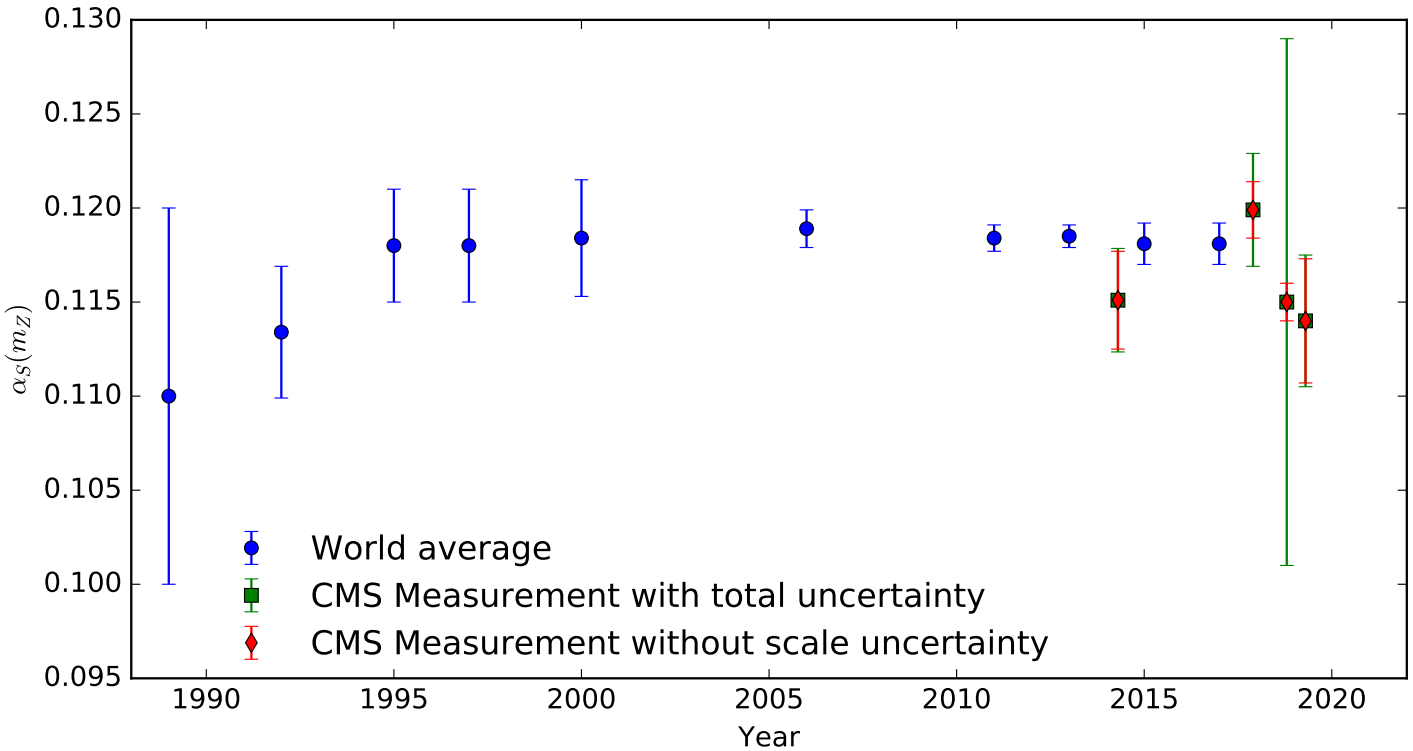
Results





- Good agreement between all four NNLO PDF sets
- Extracted α_s values (again) below the world average
- Just to pick one, NNPDF3.1 gives $\alpha_s(m_Z) = 0.1140^{+0.0039}_{-0.0033}$

Summary



- CMS results well in line with the world average
- Uncertainties much larger than in combined values
  - Theory scale unc. dominate in σ_{dijet} & jet substructure
- Similar unc. with 2.3fb^{-1} 7 TeV and 36fb^{-1} 13 TeV in $\sigma_{t\bar{t}}$
  - Syst. limited, leading uncertainties from $\sigma_{t\bar{t}}$ and PDF

References & further reading

Links to the presented CMS results:

1. "Determination of the top-quark pole mass and strong coupling constant from the $t\bar{t}$ production cross section in pp collisions at $\sqrt{s}$ = 7 TeV" arXiv:1307.1907
2. "Measurement of the triple-differential dijet cross section in proton-proton collisions at $\sqrt{s}$ = 8 TeV and constraints on parton distribution functions" arXiv:1705.02628
3. "Measurement of jet substructure observables in $t\bar{t}$ events from proton-proton collisions at $\sqrt{s}$ = 13TeV" arXiv:1808.07340v2
4. "Measurement of the $t\bar{t}$ production cross section, the top quark mass, and the strong coupling constant using dilepton events in pp collisions at $\sqrt{s}$ = 13 TeV" arXiv:1812.10505

Excellent review on α_s measurements by G. Dissertori:

- "The Determination of the Strong Coupling Constant" 1506.05407

  A contribution to: "The Standard Theory up to the Higgs discovery - 60 years of CERN", L. Maiani and G. Rolandi (editors)